INTERFERENCE POTENTIAL OF ULTRAWIDEBAND SIGNALS

PART 2: MEASUREMENTS OF GATED-NOISE INTERFERENCE TO C-BAND SATELLITE DIGITAL TELEVISION RECEIVERS

Michael Cotton,[1] Robert Achatz,[1] Jeffery Wepman,[1] and Paul Runkle[2]

This report demonstrates that digital television (DTV) susceptibility to gated-noise interference cannot be predicted by interference power characteristics alone. It was found that DTV susceptibility is also dependent on temporal characteristics of the interfering signal and the bandwidth of the DTV receiver. A test system was developed to inject interference with known characteristics into a victim receiver and quantitatively measure susceptibility. In this experiment, a C-band satellite DTV victim receiver was exposed to gated-noise interference, whose temporal characteristics are defined by gating parameters such as on-time, fractional on-time, and off-time. The specific gating parameters considered in this report include on-times of 0.01, 0.10, 1.00, and 10.00 μs and fractional on-times of 1.00, 0.50, 0.25, 0.125, and 0.0625. Results showed that DTV susceptibility was strictly dependent on average power of the interfering signal only when off-times were less than the reciprocal bandwidth of the victim receiver. For longer off-times, however, susceptibility was dependent on the temporal characteristics of the interfering signal. Moreover, high correlation was observed between susceptibility and forward error correction performance of the receiver.

Key words: digital television; interference; satellite communications; ultrawideband

1. INTRODUCTION

In April 2002, the Federal Communications Commission (FCC) released *FCC 02-48* [1] legalizing intentional, low-power ultrawideband (UWB) emissions between 3.1 GHz and 10.6 GHz for communications devices operated indoors. UWB emissions were limited to -41 dBm average power in 1-MHz bandwidth and 0 dBm peak power in 50-MHz bandwidth, where average power is measured over a 1-millisecond integration time and peak power measurement duration is unspecified. The rules define a UWB device as one that emits signals with 10-dB bandwidth greater than 500 MHz or greater than 20% of the center frequency.

The FCC rules do not specify how the bandwidth requirement is achieved, consequently allowing industry considerable breadth in choosing a modulation. This breadth is exemplified by the development of Direct-Sequence Ultrawideband (DS-UWB) and Multi-band Orthogonal Frequency-Domain Multiplexing (MB-OFDM) ultrawideband technologies. Proponents of DS-UWB and MB-OFDM both seek standardization from IEEE (Institute of Electrical and Electronics Engineers) 802.15 working group 3a on high-rate (greater than 20 million bits per

---

[1] The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, Boulder, Colorado 80305.
[2] The author is with Signal Innovations Group, Inc., Durham, North Carolina 27713.

second) Wireless Personal Area Networks (WPAN). As the name implies, WPAN is intended for short-distance (nominally less than 10 meters) wireless networking of devices such as PCs, personal digital assistants, and mobile phones.

Both DS-UWB and MB-OFDM transmitters are based on state-of-the-art integrated circuitry. DS-UWB modulation controls pulse polarity and hence supports phase shifting modulations. It achieves its ultra-wide bandwidth by transmitting sufficiently narrow pulses. MB-OFDM simultaneously modulates 122 carriers spaced 4.125 MHz apart to achieve its ultra-wide bandwidth and frequency hops the modulated carriers between non-overlapping bands.

Since previous work performed at the Institute for Telecommunication Sciences (ITS) [2 – 5] did not specifically look at susceptibility of receivers to interference from DS-UWB or MB-OFDM signals, and since there is little published information on this subject, ITS entered into a Cooperative Research and Development Agreement (CRADA) with the Freescale subsidiary of Motorola, Inc. to study how susceptibility could be quantified in terms of interference signal characteristics.

1.1. Experiment

Interference potential is a general concept where performance degradation of a victim receiver is predicted from interference signal characteristics. Interference potential is derived from numerous susceptibility tests on receivers with a variety of bandwidths and signal demodulation techniques. This report describes one such test where C-band satellite digital television (DTV) is exposed to gated-noise interference. Development of the test system and procedure was described in Part 1 of this report series [6].

In this report, only continuous- and gated-noise signals are considered as interferers. While it is unlikely that these signals will be used in communications, their similarities to DS-UWB and MB-OFDM, respectively, are unmistakable and their analytic tractability is profoundly useful. More specifically, these signals emulate the noisy nature of DS-UWB and MB-OFDM as well as the gating characteristics of MB-OFDM caused by frequency hopping in and out of a victim receiver operational band. This emulation is accomplished without the mathematical complexities associated with actual UWB modulations. Comparisons between continuous noise and DS-UWB, and gated noise and MB-OFDM, will be discussed in Part 3 of this report series.

C-band satellite television was chosen as the victim receiver for the susceptibility tests because it demodulates signals transmitted in the 3.7 to 4.2 GHz frequency range, which lies within the band allocated for UWB operation. It also uses a variety of bandwidths and signal demodulation techniques, which makes it an ideal victim receiver for the study of interference potential. Additionally, instruments capable of providing quantitative signal quality data from various receiver subsystems are readily available.

1.2. Organization of Report

The main body of this report presents DTV susceptibility data and characterization measurements for gated-noise interference with the following gating parameters: on-time (τ_{on}) = {10, 100, 1000, 10000} ns and fractional on time (ζ) = {1.0, 0.5, 0.25, 0.125, 0.0625}. These signals are denoted by the acronym GN.

Section 2 provides DTV susceptibility test results plotted two different ways. First, post-Reed-Solomon segment error rate (*SER*) and pre-Viterbi bit error rate (*BER*) are plotted as a function of interference-to-noise ratio (*INR*) to demonstrate how susceptibility depends on average power of the interfering signals. Second, *INR* and *BER* at the threshold of visibility (TOV), i.e., INR_{TOV} and BER_{TOV}, are plotted as a function of ζ to demonstrate how DTV susceptibility and forward error correction (FEC) performance depend on the gating parameters of the interfering signals.

Section 3 provides temporal and amplitude analyses of measured GN signals to demonstrate the effects of band-limiting. The temporal analysis is based on crossing statistics. Burst duration (*BD*) and burst interval (*BI*) estimates of band-limited GN signals are compared to on- and off-times of the corresponding gating functions. The amplitude analysis is based on amplitude probability distributions (*APD*s). Peak-to-average ratio (*P/A*) estimates of the band-limited GN signals are compared to corresponding ultra-wide-bandwidth *P/A* limits. Also provided in Section 3 is a spectral analysis based on power spectral densities (*PSD*s) of measured GN signals.

Section 4 discusses how DTV susceptibility depends on the characteristics of interfering signals. It summarizes the important points of the test, describes findings, and evaluates the significance and scope of the findings.

Appendices to this report contain information supporting the main body. Appendix A provides DTV susceptibility test results and signal characterization measurements for gated-noise signals that emulate MB-OFDM. Appendix B gives an overview of the test system, provides precise measurement definitions for signal-to-noise ratio (*SNR*), *INR*, *SER*, and *BER*, and provides some degree of validation via comparison of theoretical and measured DTV signal quality metrics for Gaussian noise degradation. Appendix C develops theoretical expressions for the amplitude and spectral properties of gated Gaussian noise in an ultra-wide transmission bandwidth. Finally, Appendix D provides *APD*s of the gated-noise signals in a variety of bandwidths measured at the satellite radio frequency (RF) as well as *APD*s of the signals at the first intermediate frequency (IF) in the presence of low-noise block downconverter (LNB) noise for interference powers corresponding to INR_{TOV}.